UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

LATERAL CRUSHING OF CIRCULAR RING/TUBE UNDER QUASI-STATIC LOADING

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A Dissertation submitted
In fulfillment of the requirements for the degree of Master in Mechanical Engineering
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DECLARATION

I declare that this dissertation entitled "Lateral Crushing of Circular Ring/Tube under Quasi-Static Loading" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Omar Abdulhasan Lafta Al-Khafaji

Date : ....30/9/2016..........

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering.

Signature : ....

Supervisor Name : Professor Dr. Md Radzai Bin Said

Date : ......30/9/2016......

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DEDICATION

This dissertation dedicated to my parents, for their endless love, support and encouragement along my life. I ask Allah to give you health, wellness and longevity, and keep you stalwarts to me. I love you so much.

My dearest wife, who leads me through the valley of darkness with light of hope and support. My beloved alone brother thank you for your support me. My beloved kids: Mustafa, and Marah, whom I cannot force myself to stop loving. To all my family, the symbol of love and giving. My friends who encourage and support me. All the people in my life who touch my heart.

I dedicate this dissertation.

ABSTRACT

Tubular structure is an energy absorption devices which is used to dissipate collision energy through plastic deformation of the structure. Tubular structure saves the occupants of vehicles from lateral collisions by converting the kinetic energy of crash into another form of energy to minimize the impact of accidents toward the occupants. This work presents a study on circular ring/tube under quasi-static lateral loading through experimental, numerical and theoretical tests, with and without side constraints. Mild steel ring/tube with lengths of 10 mm, 35 mm, and 60 mm respectively, with diameter of 60 mm and 1.5 mm thickness had been compressed quasi-statically. Instron machine was set to withstand maximum loading of 50 kN. The speed of compression was 5 mm/min. Different constraint angles had been used in this work to study the effect of side constraint on the energy absorption. These angles were varied from 0° to 90°, with increment 30° to examine the effect of the different angle on the energy absorption, collapse load, and specific energy absorption. ABAQUS Finite element analysis (FEA) for the ring/tube had been developed by using Dynamic/explicit code to validate experimental results. Numerical results of energy absorption and collapse load showed a close agreement with the experimental results. Theoretical results were found deviating with the experimental results. Optimum energy absorption experimentally, as well as specific energy absorption, was achieved by using U constraint. Data obtained in this dissertation hoped serve in the design of the energy absorber device in future.

ABSTRAK

Struktur tiub adalah peranti penyerapan tenaga yang digunakan untuk melesapkan tenaga perlanggaran melalui ubahbentuk plastik struktur. Struktur tiub menyelamatkan pengguna kenderaan dari perlanggaran sisi dengan menukarkan tenaga kinetik kemalangan kepada bentuk lain tenaga untuk mengurangkan impak kemalangan ke atas pengguna. Kertas kajian ini membincangkan kajian terhadap cincin bulat / tiub di bawah pembebanan sisi kuasi statik melalui eksperimen, simulasi berangka dan secara teori dengan dan tanpa kekangan sisi. Bahan keluli lembut cincin / tiub dengan panjang 10 mm, 35 mm dan 60 mm, masing-masing mempunyai diameter 60 mm dan ketebalan 1.5 mm telah dimampatkan secara kuasi statik. Mesin Instron telah dimuatkan dengan beban maksimum sebanyak 50 kN. Kelajuan mampatan adalah 5 mm/min. Sudut kekangan yang berbeza telah digunakan dalam kajian ini untuk mengkaji kesan kekangan sampingan pada penyerapan tenaga. Sudut kekangan telah diubah dari 0° hingga 90° dengan kenaikan 30° untuk mengenalpasti kesan sudut yang berbeza pada penyerapan tenaga, beban runtuhan dan penyerapan tenaga tentu. ABAQUS, analisis unsur terhingga (FEA) bagi cincin / tiub telah dibangunkan dengan menggunakan kod Dinamik / tersurat untuk mengesahkan keputusan eksperimen. Keputusan berangka penyerapan tenaga dan beban runtuhan menunjukkan keputusan yang hampir sama dengan keputusan eksperimen. Keputusan teori didapati tersisih daripada keputusan eksperimen. Penyerapan tenaga optimum ujilleji serta penyerapan tenaga tentu telah diperolehi menggunakan dengan kekangan U. Maklumat yang diperolehi dalam kajian ini diharap dapat membantu dalam reka bentuk peranti penyerap tenaga pada masa depan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
EST	Equivalent Structure Technique
FEA	Finite Element Analysis
FKM	Faculty of Mechanical Engineering
GMC	General Motor Company
NHTSA	National Highway Traffic Safety Administration
SEA	Specific Energy Absorption
UTeM	University of Technical Malaysia Melaka

LIST OF SYMBOLS

P_o	Collapse load
R	Radius of ring/tube
M_P	Fully plastic bending moment
σ_y	Yield stress
t	Thickness of specimen
h	Length of specimen
α	The angle of constraint
P	Crushing load
D	Diameter of ring/tube
W	Total energy absorbed
S_b	Crush distance
M	Mass of the structure
b/a	a, b are horizontal and vertical semi-axes of the ellipse

LIST OF PUBLICATIONS

Minah Mohamad Fareed, **Omar Abdulhasan lafta,** Md Radzai. (2016). Axial Crushing Of Circular Tube Under Quasi-Static Loading. *The 4th International Conference on Engineering and ICT (ICEI) 2016*, Melaka, Malaysia.

Omar Abdulhasan Lafta, Minah Mohammed Fareed, Md Radzai Bin Said. (2016). Energy absorption capability of mild steel ring/tube under quasi-static lateral loading. *2nd International Conference on Automotive Innovation & Green Energy Vehicle (AIGEV) 2016.* Malaysia Automotive Institute MAI, Cyberjaya, Selangor Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Background

Safety features in vehicles have been included in the design of automobiles since the first collision that took place in New York City in 1889 (Du et al., 2004). Over the last century, the safety of the occupants is considered an important target in the design of the ground transportation vehicles. The development of occupant's safety took place in three historical periods, from early 1935 to 1966 (Du et al., 2004).

The first period since early of 1935 was the era of growth and understanding the process of a vehicle collision. The collision of the vehicle can be defined as a consequence circumstances which create an irregular condition towards the body of a vehicle. Collision might occur either between two vehicles or a vehicle in a fixed obstacle, and the result will be the deformation of the vehicle structure. When collision force surpasses the energy absorption, the capability of structure will lead to occupants' injuries or even death. This period saw the improvement on the basic requirements, such as the headlamp to provide night visibility and reduce the tire pressure to prevent loss control of vehicle and to fix the laminated glass to decrease facial accident.

The second period was between, 1936 and 1965. This period saw the improvement on the passive safety devices (additional safety devices to prevent catastrophes of collisions), dual windshield wipers and the resistance of penetration of the windshield glass. General Motor Company (GMC) produced the first car which was used for the frontal crash to the rigid barrier, where the performance of this car evaluated by observation. The safety belt served as a safety device in 1956 attempting to fix a passenger in his position when a collision occurs.

The third period was in 1966 when the law of the highway was signed by President Lyndon Johnson. This law was considered as an approval to create the National Highway Traffic Safety Administration (NHTSA), which involves compulsory standards of the vehicle crashworthiness and safety ways to avoid the crash. Occupant's safety was considered before 1966, where it is one of the important processes in vehicle development without focusing on the roads and highway requirements. The combination of vehicle safety technology with good highways surfaces, improved road visibility consequently lead to the decreased rate of road fatalities. According to the public health statistics, the crash of vehicle occupied the fourth main reason of death after stroke, heart disease and cancer.

Today, automakers seek to focus on the crashworthiness, which is defined as passive safety to save the occupant's life by withstanding the structure of the static and dynamic loads. The requirements of the vehicle structure should involve formability, corrosion resistance, recyclability and adequate strength when undergoing crash load to absorb the energy of crash, to provide sufficient survival space for occupants.

Crashworthiness of the structure of vehicle can be evaluated through experimental and analytical tests. The first evaluation began experimentally in 1930 through rollover tests. Nowadays, tests involve three types: component tests, sled tests, and full-scale obstacle impacts, in addition to the use of the latest simulation techniques, or both of them (experimental and simulation) to determine the possibility of human injury when exposed to real crash circumstances. The objective of crashworthiness is an enhanced vehicle structure that can absorb the kinetic energy of crash by controlling the vehicle's plastic deformation while maintaining sufficient space; therefore, the remaining energy can be managed by the control system to minimize the crash load that may transfer to the vehicle occupants. As mentioned, crashworthiness is the quality of response of the structure to deform plastically during a collision. Crash energy can dissipate plastic deformation and fracture (Huang et al., 2002). The collisions of vehicles are divided into four types: front, rear, side, and rollover. Figure 1.1 presents some types of cars that used the tubular crashworthy structure in the lateral direction. The results of side accidents due to impact are harmful to the vehicle's occupants (Fildes et al., 2003).

This dissertation discusses the lateral condition of the circular mild steel ring/tube under quasi-static loading. The material used in the energy absorption field must deform plastically in a short time to absorb the kinetic energy of crash to reduces harm towards the occupants, therefore mild steel is proposed as an energy absorbing material.

The advantage of the quasi-static method is to ensure that the deformation of metal is lesser than the level of the applied load. Many studies used metallic materials with different shapes because of easy manufacturing, for instance by Niknejad and Rahmani, (2014) who studied the hexagonal empty and foam-filled column theoretically and experimentally, Olabi et al. (2008) investigated the nested circular mild steel tube experimentally and numerically, while Wilbert et al. (2011) looked into aluminum honeycomb experimentally.etc. In this study, the analysis on energy absorption was proceeded with different lengths of mild steel specimens, and different angle constraints were collected to explain the comprehensive picture of the load- displacement characteristics.

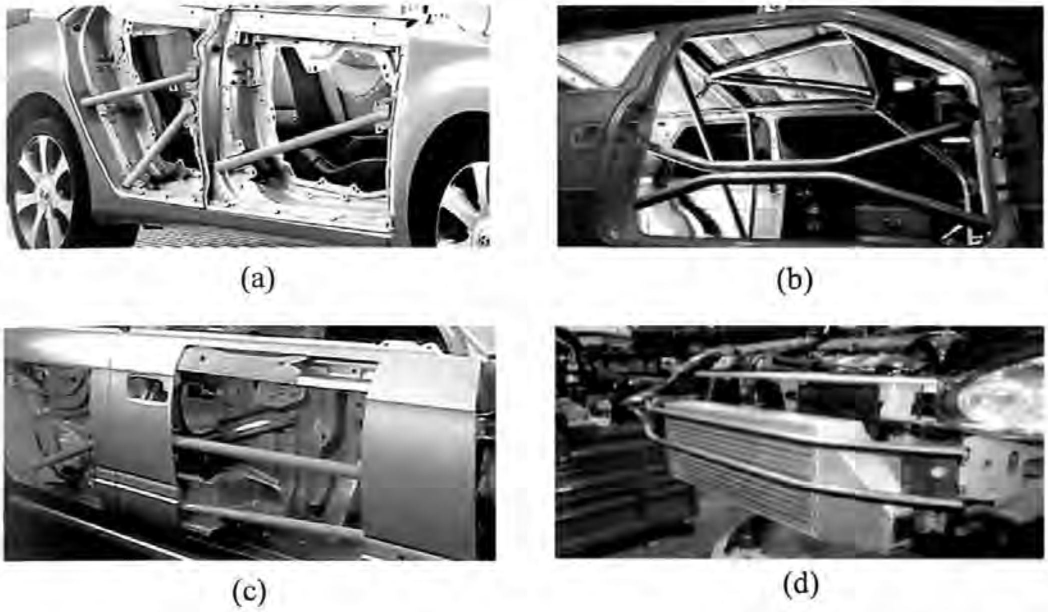
(a) (b) (c) (d)

Figure 1.1: (a) Hyundai Elantra (The tech journal, 2012), (b) Volkswagen GTI (Volkswagen MKII GTI, 2013), (c) GMC superban (Side door beams, 1993) (d) Dodge (Dodge, 2016)

1.2 Problem Statement

Various studies on energy absorption by a tubular structure have been done by previous researchers to minimize the risk towards passenger by dissipating the kinetic energy of collision by plastic deformation of the structure. Tubular structure is preferred by its easy manufacturing, and the fact that it is commonly used (Hamouda, 2007; Niknejad et al., 2012). These different shapes of tubular structures motivate designers to discover: which shape can absorb further energy, which answer to suitable direction of energy absorber device, dimension, position, and optimal angle to deform the structure to dissipate collision energy. Still, the energy absorption structure requires a wide range of studies and additional analysis to achieve the desired purpose. This study attempts to find out the effect of circular ring/tube with different lengths and angles on the amount of energy absorbed consequently to use it as an energy absorption device that absorbs adequate energy to keeps vehicle occupants survive.

1.3 Objective

The objectives of this research are explained below:

i. To study the load-displacement curves characteristics from experimental, theoretical and simulation tests with and without side constraints.

ii. To study the effect of different length and different side constraint on the collapse load, energy absorption and specific energy absorption.

1.4 Scope

This study involves experimental, theoretical and numerical tests on the mild steel circular ring/tube with having 10, 35, and 60 mm of length, 60 mm diameter and 1.5 mm thickness, subjected to a quasi-static lateral loading with velocity of 5 mm/min, by using universal Instron machine (5585) static type at room temperature. Numerical simulation tests were carried out using Abaqus 6.14.1 software. All tests were carried out with and without side constraints. These constraints had two shapes, which where U-shape with 90° angle and vee-block of 30° and 60°. These parameters had been selected to determine the highest energy absorption of each length, with and without constraints, to use it as a structure of energy absorber. The ultimate target is to use this structure to save the occupants of the vehicle when a collision occurs. This work presents a numerical and theoretical methods for all parameters used in the experiments to obtain accurate result and to identify the difference of percentage between them.

1.5 Significant of study

This study contributes by providing further information about tubular structures (mild steel) used in the crashworthiness field to improve energy absorption characteristics under quasi-static lateral loading. The aim is to study the amount of energy capable to be absorbed by this structure, which allows relevant parties to improve the protection of this structure from damage when it is used as energy absorber under dynamic loading in automobile and industry application. In addition, in this research, different lengths of mild steel tube had been used to study the effect of variable length on energy absorption. Furthermore, various angles had been used in this study to produce an efficient angle that absorbs a large amount of energy.

1.6 Dissertation outline

Chapter 2 includes the previous studies concerning energy absorption. This chapter focuses on the crashworthy structure that is compressed quasi-statically with and without constraints. In addition, load-displacement curve characteristics had also been taken into consideration. Furthermore, the factors affecting the energy absorption and the numerical previous studies are also mentioned. Finally, this chapter offers some essential mathematical and numerical information which proves to be useful for this dissertation.

Chapter 3 involves experimental procedure that includes the selection of material. The importance of the tensile test is also explained in this chapter. Identification of dimensions of the specimens test and cutting, and grinding of specimens used with and without constraints under lateral quasi-static loading are also discussed. In addition, the weighting of specimens deemed essential to calculate specific energy absorption as well as, the design and manufacture of the constraints with different angles are elaborated in this chapter.

Chapter 4 involves the simulation of the experimental work by using ABAQUS software through follow the modules of the program. In this chapter, modelings of all the components of the Instron machine used to compress the specimens to simulate the real work are discussed in detail.

Chapter 5 discusses the experimental, numerical and theoretical results. The differences between all these results are discussed in this chapter. The comparison between all specimens with different length and angles in term of the collapse load, energy absorption and specific energy absorption are explained in this chapter.

Chapter 6 presents the main achievements of the current research and suggestions of work to be conducted in the future, which concludes the dissertation.